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IPHC oceanographic data collection program 2000-2014

by

Lauri Sadorus[1], Jay Walker[1], and Margaret Sullivan[2]

[1]*International Pacific Halibut Commission*

[2]*University of Washington, Joint Institute for the Study of the Atmosphere and Ocean, as part of NOAA/PMEL EcoFOCI program*

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INTERNATIONAL PACIFIC HALIBUT COMMISSION
2320 WEST COMMODORE WAY, SUITE 300
SEATTLE, WASHINGTON 98199-1287, U.S.A.
http://www.iphc.int

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Contents

Abstract

In response to a desire to incorporate oceanographic parameters into Pacific halibut research, the International Pacific Halibut Commission (IPHC) initiated a pilot program in 2000 to test the practicality and utility of oceanographic data collection during the annual IPHC fishery-independent longline survey. Following the success of the pilot program which lasted a number of years, the project was expanded in 2009 to include all IPHC survey vessels and management areas. This report outlines the history of the project from its origins through 2014. A total of 8,008 useable profiler casts were collected during that time. Based on those data, halibut residing off the west coast of the U.S. and British Columbia experienced warmer termperatures, higher salinity, lower dissolved oxygen, and more acidic conditions relative to other areas surveyed. In the Gulf of Alaska, near-bottom temperatures were lower than off the west coast but higher than the Bering Sea. Dissolved oxygen and pH were both higher than off the west coast and salinity was lower. In the Bering Sea, temperatures were cool, dissolved oxygen was the highest of the three areas, salinity was lower than the west coast but higher than the Gulf of Alaska, and pH was comparable on average, to the pH found in the Gulf. Also included in this report are the results of a study conducted in 2012 examining the proximity of the profiler to the bottom at its maximum casting depth. This study found that there is variability across vessels and depth, but on average, the profiler comes within about 10 m of the bottom and adequately represents the conditions experienced by Pacific halibut caught on the survey gear.

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Introduction

Pacific halibut (*Hippoglossus stenolepis*) is a large flatfish that inhabits the continental shelf of the north Pacific Ocean and Bering Sea from northern California to Japan (IPHC 2014). The International Pacific Halibut Commission (IPHC) has managed the halibut stock in United States and Canadian waters since 1923. The ongoing sustainable utilization of the resource has been successful due in large part to cooperative involvement of scientists, stakeholders, and others to map out innovative ways to approach research and management. IPHC scientists recognized in the late 1990s that monitoring environmental conditions coincident with catch might eventually contribute clarity to the stock assessment and aid in the evaluation of harvest strategies. This step seemed particularly important given that the effects of climate change were already being documented around the globe (IPCC 1995), and baseline environmental data for North American continental shelf bottom habitats were extremely limited.

Until recently, there was only minimal oceanographic information collected coincident with commercial fishing or scientific fisheries surveys due to high platform and equipment costs, difficult sampling protocols, and lack of monitoring tools appropriate for non-oceanographic vessels. Technological advancements allowed for the development of affordable, practical instrumentation that could be deployed from a fishing vessel, specifically water-column profilers which can be deployed from the deck of a vessel and descend to the bottom, collecting data throughout the water column. The IPHC used these advancements to implement a program where environmental data are collected alongside species catch data during the IPHC setline survey (Fig. 1; reproduced from Henry et al. 2012), so that data directly reflect the environmental conditions fishes are experiencing. Additionally, because of the geographic extent of the IPHC survey and annual frequency, the data are of interest to scientists worldwide. To that end, the IPHC committed to making the data freely accessible to the public. This report provides the history and basic results of the IPHC oceanographic monitoring program from the time when the pilot program started in 2000, through 2014, which was the sixth year of coastwide data collection.

Fishery management uses for oceanographic data

Current fishery management focuses on age-class and length-class determinations along with removals from the stock as the primary means of predicting how many fish are available for harvest. Managers know that commercial catches can vary temporally and spatially based on a variety of factors, and are becoming increasingly aware of fluctuating oceanographic conditions and their impacts on fishes. It has been shown through recent studies (e.g. Hurst 2007, Keller et al. 2010, and Prince et al. 2010) that environmental factors affect behavioral, distributional, and fitness characteristics in marine organisms. Using data collected by the IPHC profiler program, Sadorus et al. (2014) found that adult Pacific halibut appear to avoid areas of low dissolved oxygen concentration, and that other variables such as temperature and depth also play a role in their distribution.

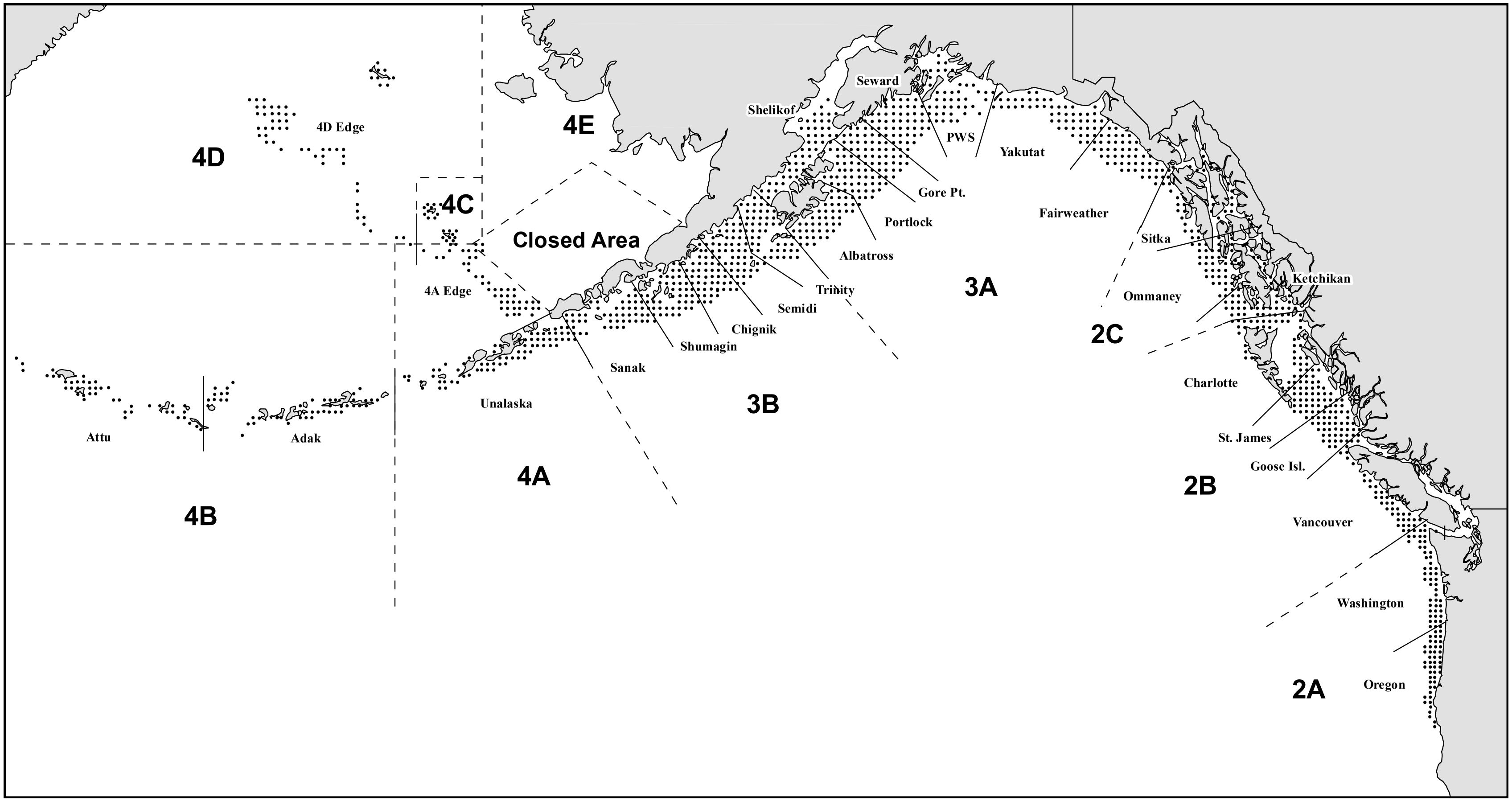

Figure 1. IPHC survey stations sampled in 2012. The number/letter combinations are IPHC regulatory (management) areas and smaller area designations are survey regions. (Figure reproduced from Henry et al. (2013)).

Additionally, results from setline surveys and commercial catch monitoring may be affected by varying oceanographic conditions that induce changes in animal behavior. There is evidence to suggest that both temperature and low dissolved oxygen (Stoner et al. 2006) affect the feeding behavior of halibut which, in a longline survey setting, may impact how halibut react to the baited gear (Sadorus et al. 2014). The longline fishing gear used in this study is passive, indicating that a particular behavior from the fish is required to bite the hook. If that behavior varies under different oceanographic conditions, then the fishing gear may not be equally effective across all grounds. In that case, the survey results will not equally reflect the amount of biomass over the survey range. Knowing how oceanographic variables affect animal response to the fishing gear is necessary to interpreting these data accurately.

Area description

The north Pacific Ocean and Bering Sea are home to a wide range of oceanographic features and conditions. The West Coast is characterized by a collection of major ocean currents. Water from the North Pacific Current flows eastward toward the coast of Vancouver Island, feeding the California Current to the south and the Alaska Current flowing northward (Fig. 2). Features along the U.S.A. and Canadian coasts include seasonal and intermittent coastal upwelling, a prominent, stationary eddy feature, major estuarine inputs, and a narrow continental shelf with numerous canyons and banks to the south. Summer upwelling is strong off the coasts of California, Oregon, and Washington States, and to a lesser degree off southern Vancouver Island. The upwelled water is largely from the California Undercurrent which flows up from the south, and has relatively high salinity, temperature, and nutrient values, and low dissolved oxygen (Hickey and Banas 2003).

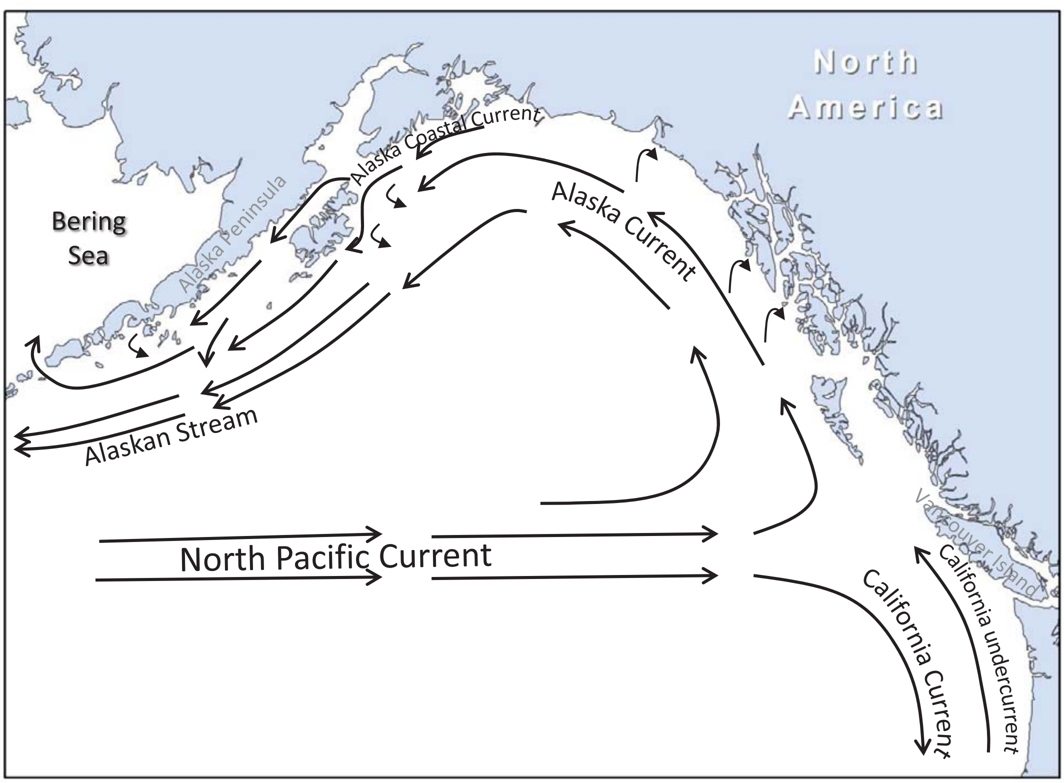

Figure 2. Major oceanic currents in the Gulf of Alaska and U.S. West Coast.

Further north in the Gulf of Alaska, a number of features contribute to the transport of nutrients and to high environmental variability. Although much less intense than further south, there is episodic upwelling and downwelling, in addition to eddies, coastal jets, bathymetric steering, freshwater input via numerous bays and inlets, and submarine canyons. At the head of the Gulf of Alaska, the Alaska Current becomes the Alaskan Stream which narrows as it flows southwest along the slope of the Alaska Peninsula and Aleutian Islands (Ladd et al. 2005). Inshore of the Alaskan Stream, the Alaska Coastal Current flows through Shelikof Strait and along the Alaska Peninsula (Stabeno et al. 1995).

The Bering Sea (Fig. 3) is characterized by a wide, shallow shelf of less than 100 m in depth in the east. Seasonal sea ice reduces the salinity and temperature of surface waters as it melts, and contributes to stratification of ocean layers. Submarine canyons exist along the shelf edge, and a persistent cool or "cold pool" of ocean water with temperatures less than 2^{o}C is typically found in the subsurface layer (Takemouti and Ohtani 1974). The Bering Slope current flows northward along the eastern Bering Sea shelf edge, and the Aleutian North Slope current flows eastward along the north side of the Aleutian Islands (Stabeno et al. 1999).

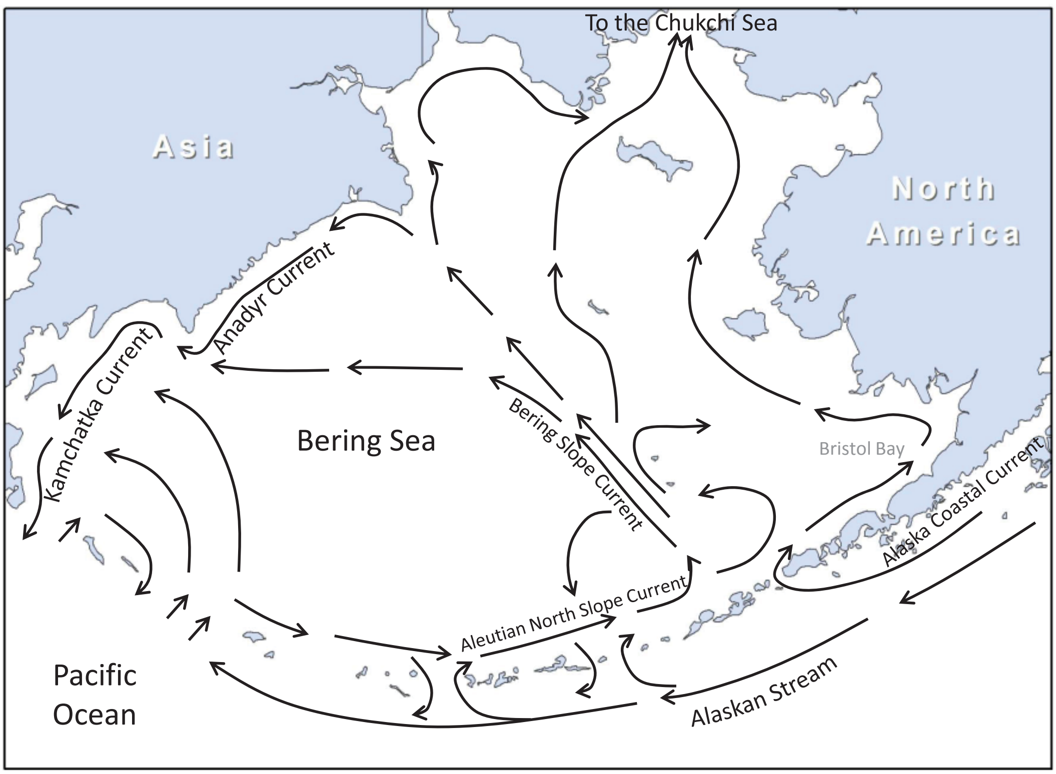

Figure 3. Major oceanic currents in the Bering Sea and along the Aleutian Islands.

Profiler program history

In 1998, the IPHC expanded its setline survey operation to cover the continental shelf from southern Oregon to the Aleutian Islands and Bering Sea. This survey has been conducted annually since and takes place from June to August each year. The area is generally divided into 27 survey regions (although in some years more regions are included to study areas of special interest) and the work is conducted by chartered, commercial longline fishing vessels. Fishing takes place on a 10x10 nautical mile (nmi; 1.852 km) grid from roughly 30-500 m depth (IPHC 2014). Halibut grounds surveyed less frequently include the Bering Sea flats (Bristol Bay), northern California, Puget Sound, and stations placed outside the standard depth range of the regular survey (Fig. 1). Because the majority of the halibut grounds are surveyed annually and systematically, it was a logical next step to expand data collection to include variables in addition to catch.

Profiler pilot project: 2000-2004

In 2000, a water-column profiler, manufactured by Sea-Bird Electronics[1], was purchased for deployment on the IPHC survey. The goal was to test the unit, but also to test its use on the deployment platform (a chartered longline fishing vessel) to ascertain whether deployment could be accomplished with minimal disruption to the other operations. The information here summarizes project details provided in Hare (2001).

The profiling unit (model SBE19) measured pressure (equivalent to depth in meters), temperature (°C) and conductivity which allowed for calculated salinity values (practical salinity units – psu). The profiler was equipped with floats at the top and an anchor at the bottom attached via a weak link in case the anchor became attached to the bottom and the unit needed to be pulled free. A line connected the top of the unit to the vessel (Fig. 4). Deployment was accomplished by switching the profiler to the "on" position, lowering the unit over the side of the fishing vessel and releasing it to drop through the water column until the line went slack indicating that the anchor had hit bottom. The floats at the top offset the weight of the anchor, allowing the instrument to

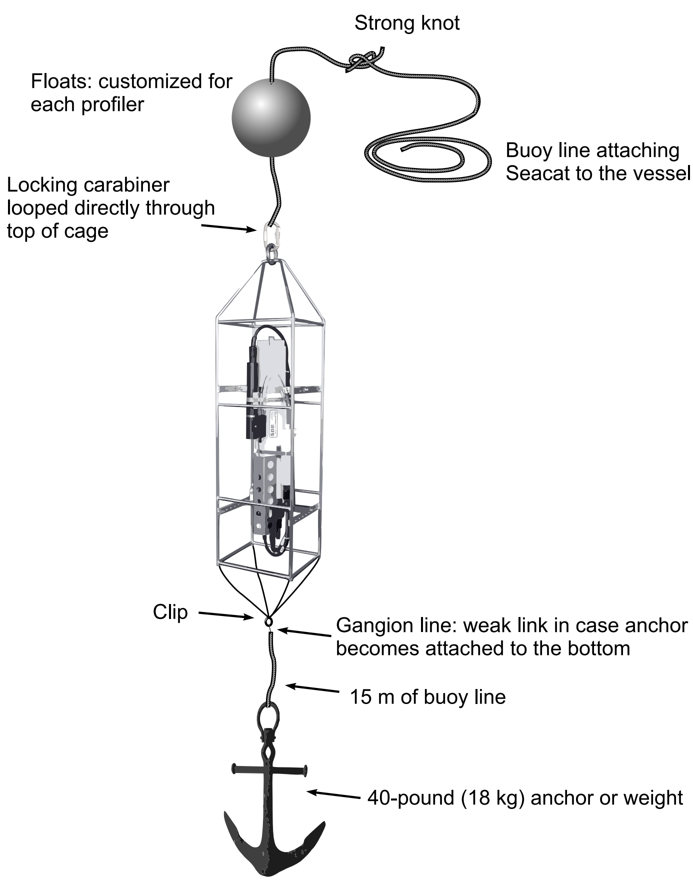

Figure 4. Schematic diagram illustrating the water column profiler configuration used for deployment from IPHC setline survey vessels.

[1] Sea-Bird Electronics, 13431 NE 20th St, Bellevue, WA 98005, USA

descend at an optimal speed of 1-2 m/s. As the anchor hit bottom, the floats provided positive buoyancy for the unit, effectively pulling upward on the instrument and avoiding impact with the bottom and possible damage. This profiler model collected data at half-second intervals.

Once the profiler was back aboard, the sensors were rinsed to remove salt and debris and the unit was prepared for the next cast. Data were uploaded periodically via a serial cable that connected the profiler to a laptop computer. Sea-Bird software (*Seaterm*) enabled the retrieval of the data for each cast in .hex format. After data retrieval, the unit was reset allowing for the full memory to be available for subsequent casts. The cast data were then converted into a readable format (.cnv) using Sea-Bird's *SBEDataProcessing* software.

During the first year, successful profiles were made at 120 out of a possible 130 stations and included a variety of station locations and deployment conditions. The project goals were met and the test was considered a success.

The following year, in 2001, the profiler was deployed on two separate vessels. To ensure consistent water flow through the sensors, a Sea-Bird SBE 5T pump was added to the instrument. This required an additional deployment step of holding the profiler at the surface to prime the pump before release. That year 100 profiles were successfully completed out of 126 possible profiles. One entire trip was not profiled due to problems with the power supply (Hare 2002).

In 2002, only a small number of profiles (25) were collected after the companion laptop failed. However, in 2003, the profiler was deployed from a vessel surveying the Bering Sea with a 91% success rate, i.e. 120 profiles (Hare 2004). In 2004, a mechanical difficulty with the unit required removal for servicing during the season. Once the problem was fixed, the profiler was returned to the vessel. Due to time constraints, the profiler was deployed only once a day for the rest of the charter and resulted in 14 profiles (Hare 2005).

Second phase: 2005-2006

Beginning in 2002, particularly low dissolved oxygen (hypoxia) had been detected each summer off the coast of Oregon (Chan et al. 2008). Although hypoxia had been historically detected off the coasts of Washington and Oregon (Connolly et al. 2010), the recent events tended to be more intense and stretched to shallower depths, often leaving dead crabs and other invertebrates in its wake.

In 2005, the IPHC added a dissolved oxygen sensor (SBE 43) to the existing profiler for two reasons: to test how well the SBE 43 fared under survey conditions and also to study whether hypoxia had become a factor in the waters immediately north of the documented area. Also that year, the IPHC began deploying the profiler off of the coast of Vancouver Island and Queen Charlotte Sound, with the intent of deploying there each year and thus building an area time series.

A factory malfunction of the SBE 43 instrument in the first year rendered the data unusable, but the sensor itself proved as sturdy and easy to work with as the base SBE19 unit. Sea-Bird Electronics made the necessary repairs and the sensor was deployed successfully the following year.

Coastwide expansion: 2007-2014

Interest in expanding the collection of oceanographic data to important fishing grounds in the north Pacific and Bering Sea increased over time, both from scientists and resource stakeholders. In 2007, the IPHC received a grant for $26,000 from the Oregon Department of Fish and Wildlife Restoration and Enhancement Program for the purchase of one profiler to be deployed off the West Coast (Grant 54008 945132-09). By this time, Sea-Bird Electronics was manufacturing an updated model, the SBE19plus, which collected four measurements per second, instead of two, and allowed additional auxiliary sensors. IPHC purchased a unit complete with auxiliary sensors to measure dissolved oxygen (SBE 43), pH (SBE 18), and fluorescence (WETLabs ECO-FLRTD). Specifications for the instruments can be found in Table 1.

Table 1. Model names and manufacturer-published accuracy specifications of oceanographic instruments used in this study.

Instrument/Model	Initial accuracy	Resolution	Stability
SBE19plus V2 CTD			
Pressure (strain gauge db)	1	0.02	1/year
Temperature (°C)	0.005	0.0001	0.0002/month
Conductivity (S/m)	0.0005	0.00005	0.0003/month
SBE19plus CTD			
Pressure (strain gauge db)	1	0.02	0.5/year
Temperature (°C)	0.005	0.0001	0.0002/month
Conductivity (S/m)	0.0005	0.00005	0.0003/month
SBE19 CTD			
Pressure (strain gauge db)	2.5	0.15	None posted
Temperature (°C)	0.01	0.001	
Conductivity (S/m)	0.001	0.0001	
Dissolved oxygen – SBE 43	2% of saturation		0.5% per 1000 hours
pH – SBE 18	0.1 pH		variable
Fluorescence – WETLabs ECO-FLRTD		Sensitivity	Range
		.02 mg/m^3	0-125 mg/m^3

In late 2008, IPHC received a grant from the National Oceanic and Atmospheric Administration (NOAA) for $537,055 (Grant NA 08NMF4720648) for the purchase of 14 profilers, 14 companion laptops, and four years of operating and data processing costs. This grant allowed the expansion of the profiler project to extend to all vessels and areas surveyed by the IPHC. IPHC purchased the latest model profiler (SBE19plusV2) equipped with auxiliary sensors for dissolved oxygen, pH, and fluorescence (Fig. 5). The project was launched coastwide in 2009.

The simultaneous deployment of profilers from many vessels necessitated the need for standardized maintenance and deployment protocols across areas and years. Protocols are recorded in a manual which is updated each year and given to survey biologists. Additionally, survey samplers are trained annually on deployment and retrieval of data from the units. Standardized protocols include:

- Use of weight and float assembly to ensure the profiler does not impact the bottom
- Target descent rate of 1-2 m/s
- Continual in-season maintenance steps to ensure maximum profiler efficiency
- Deployment of the profiler just prior to haul back of survey gear at every station
- Upload of casts to the companion laptop once daily to minimize risk of data loss
- Reliable laptop backup system and frequent backups to minimize risk of data loss
- Regular quality control of data to ensure sensors are working properly
- Field calibration of pH sensor since 2011
- Annual factory maintenance and calibration

Additional data recorded by the vessel's captain during deployment includes: depth (as determined by the vessel depth-finding instruments), latitude, longitude, co-occurring set number, station number, vessel, region, and trip number. Samplers add this information to each profile data file as it is uploaded to the laptop computer.

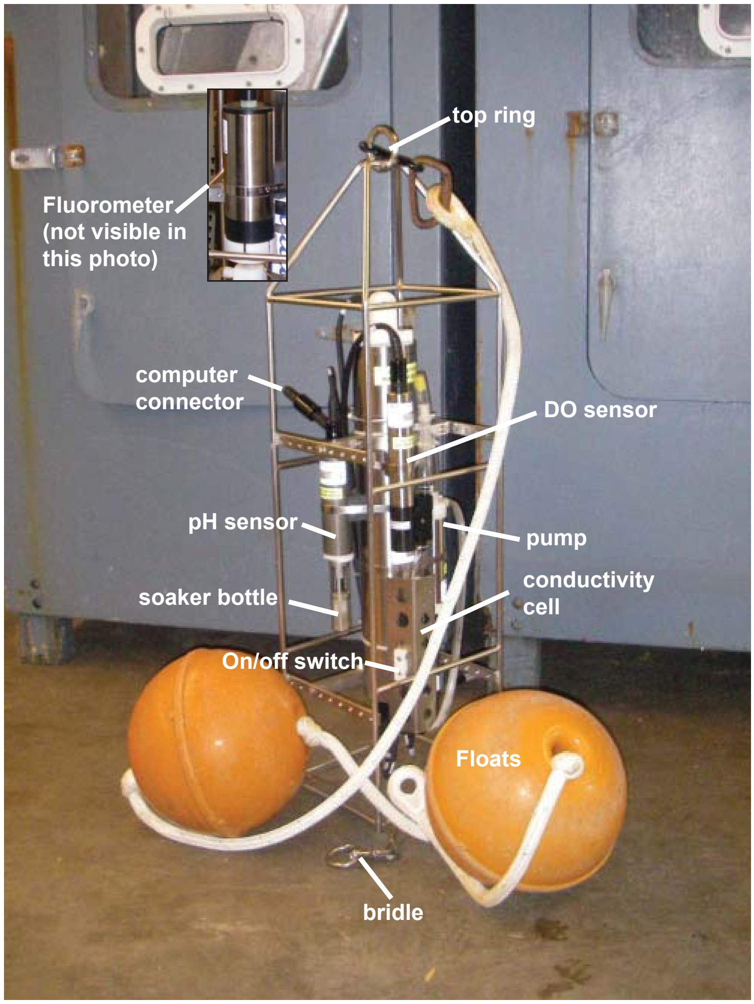

Figure 5. Sea-Bird water column profiler used by the IPHC during the annual setline survey.

The profilers are robust and can withstand a wide range of conditions. Repairs have been minimal and most often involve delicate parts of the instruments such as deteriorating electrodes and torn membranes within the sensors. Annual factory calibrations ensure sensor accuracy.

Between 2009 and 2014, two profilers were lost at sea. In 2009 off Kodiak Island, AK a communication error on deck resulted in a profiler being released over the side before being tied off to the vessel. Attempts to retrieve it were unsuccessful. The incident inspired a more strict deployment protocol to mitigate operator error. In 2011 off Adak Island, AK a profiler was being retrieved via the vessel's gurdy. Currents were strong, the profiler line drifted under the vessel, and the line was cut, presumably by line cutters around the propeller. Attempts at retrieval were unsuccessful. A third profiler was lost in the Bering Sea in 2014 when the float line was attached incorrectly and the line separated from the vessel. This profiler was retrieved after the vessel set longline gear around the unit and hauled/dragged across the profiler location. The profiler was snagged by a hook and brought back aboard without damage.

Companion laptops

Alongside the purchase of profilers in 2009, was the purchase of an equal number of laptop computers to accompany each profiler into the field. The laptops were used to program the profilers for data collection, upload daily data while in the field, and diagnose or troubleshoot any problems the profilers had. Additionally, they were used to perform periodic quality control checks on the data files, store the results of pH field calibrations for later use, store all of the profiles from the current season, and allow samplers to communicate remotely with the IPHC office while in port.

The programs used with the profilers for data collection, processing, and pH calibration were created by Sea-Bird Electronics and are updated annually as needed. Specifically, *SeaTerm* is used for data acquisition, *SBE Data Processing* modules are used for raw data conversion and data processing (.hex to .cnv), and *Seasave* is used for pH calibration.

At-sea conditions often include rough weather and substantial vessel movement. The laptops are ordinarily located in the wheelhouse which keeps them secure and free of excessive moisture. However, ship motion in rough weather and rigorous field use occasionally resulted in failed hard drives which in turn resulted in both having to replace the laptop and loss of any data that had not yet been sent to the IPHC office.

In 2011, to make the laptops more robust, the hard drives were replaced with solid state drives. This enabled the computers to sustain light to medium impacts without incurring damage. Additional backup procedures were added to avoid data loss in the event of hard drive failure.

One laptop was lost in transit in 2011. Occasional laptop replacement has been necessary as a result of wear and tear over time. Overall though, the laptops have met or exceeded their expected life span during the first six years of the coastwide program.

NOAA data partnership

A facet of the original NOAA grant was making the profiler data available to researchers worldwide. IPHC partnered with NOAA's Pacific Marine Environmental Laboratory (PMEL) to process and publicly post the annual data sets during the grant period. This partnership has continued since the grant expired.

In the field, header information was added to each cast at the time of upload to the laptop computer from the profiling unit. Header information included latitude, longitude, set number, station number, trip number, vessel code, region code, and bottom depth as measured by the fishing vessel depth finder. After the field season, raw data, including the input header information, from the profiler instruments were converted from engineering units to the Sea-Bird converted (.cnv) file format at IPHC which are human readable. Pre-processing at IPHC included header data checks, mapping stations for geolocation review, mapping variables to detect any obvious sensor malfunctions that went undetected in the field, and any other editing needed. The final .cnv files, as well as the .hex and .xml files, were delivered to NOAA's PMEL. A configuration file, location map, and a metadata file accompanied each data set per survey region. The metadata Microsoft Word documents were modeled after the NOAA/National Ocean Data Center standard format.

Once the data arrived at PMEL, they were processed using Sea-Bird Standard Data Processing software. This level of processing corrected for differences in temperature and conductivity sensor response time and location on the profiler, and for ship motion and noise (see processing manual and Sea-Bird website, http://www.seabird.com/software/sbe-data-processing). The software applies calibrations, splits the data record into up- and down-casts, calculates derived variables (e.g. salinity from conductivity), and averages values to a 1-meter grid. Data were plotted for review, looking for acceptable output, spurious outliers, sparseness, and unusual patterns. Problematic data points and segments were hand corrected or removed. Near-surface data values were often extrapolated to the surface. Processed files were retained both as text files, and converted to binary NetCDF formatted files that included a subset of metadata within the file header.

Due to the nature of this field program, water samples could not be collected, therefore neither dissolved oxygen nor chlorophyll *a* data could be sample-calibrated, and notes were added in the metadata to that effect. Sea samplers were instructed to perform pH field calibrations, but these have sometimes proven to be difficult given varying vessel conditions and platforms. The result was irregular useable calibrations, but corrections were applied post-season when possible. The SBE 18 pH sensor was the most accurate profiling unit sensor available for the instrument configuration and depths being profiled at the time this report was published. However, while data provide general habitat characteristics for fishes, they are of questionable quality and precision for purely oceanographic applications.

After the data were fully reviewed and the metadata were updated, individual data files were zipped together, creating a separate text and NetCDF file. These were posted on a dedicated PMEL web page (http://www.ecofoci.noaa.gov/projects/IPHC/efoci_IPHCData.shtml) for public access and download. Maps and metadata were also posted, and the site includes project information and links.

Reconciling bottom depth in relation to profiler depth: Field experiment using Star-Oddi depth sensors

Pacific halibut live on and near the bottom so the question of bottom depth in relation to profiler data collection is relevant since the IPHC's intention is to use the profiler data to examine Pacific halibut habitat. During deployment, the rigging of the profilers is such that an anchor attached to the base of the unit hits bottom and the floats then render the instrument positively buoyant. The downward momentum of the profiler carries it some distance after the anchor has hit, but the rigging is designed so that there is enough line between the profiler and anchor so that the profiler never contacts the bottom. However, because of the extra distance that the profiler travels after the anchor hits it was unclear how close the profiler actually came to the substrate. Bottom depth at the cast location is collected using the depth-finding instruments on board the vessels. These tend to be imprecise and variable among vessels, and differences had not been quantified. During the original pilot work in 2000, the researchers used a rough estimate that the profiler came within about 10 m of the bottom. With changes in unit weight as sensors were added and varying depths, it was unclear if this estimate remained true over time and over varying circumstances.

To add clarity to this issue, in 2012 the IPHC conducted a small-scale experiment during the summer setline survey. The primary objective was to determine how close the profilers came to the ocean bottom during deployment. Secondary objectives included determining the accuracy of the vessel depth-finding instruments as a measure of bottom depth, and quantifying the variability of the vessel depth-finding instruments among vessels.

Methods

For this experiment, Star-Oddi[2] depth sensors (DST logic model) (Fig. 6) were used in addition to the profiler instruments and vessel depth-finder readings. The accuracy rating of the Star-Oddi sensors, determined by the manufacturer, was $\pm$0.4% ($\leq$ 270 m) and $\pm$0.5% (> 270 m), i.e. within 0.15-2.50 m depending on depth.

The Star-Oddis were attached to the anchor of the profiler rigging with a carabineer and duct tape to ensure contact with the bottom. Each sensor was programmed to collect data once per second at depths below 10 m and to shut off when the profiler returned to the surface.

For this analysis, Star-Oddi bottom depth was assumed to be equivalent to true bottom depth since the instrument error was much less than the apparent variability of the vessel depth-

[2] Star-Oddi, Skeidaras 12, 210 Gardabaer, Iceland

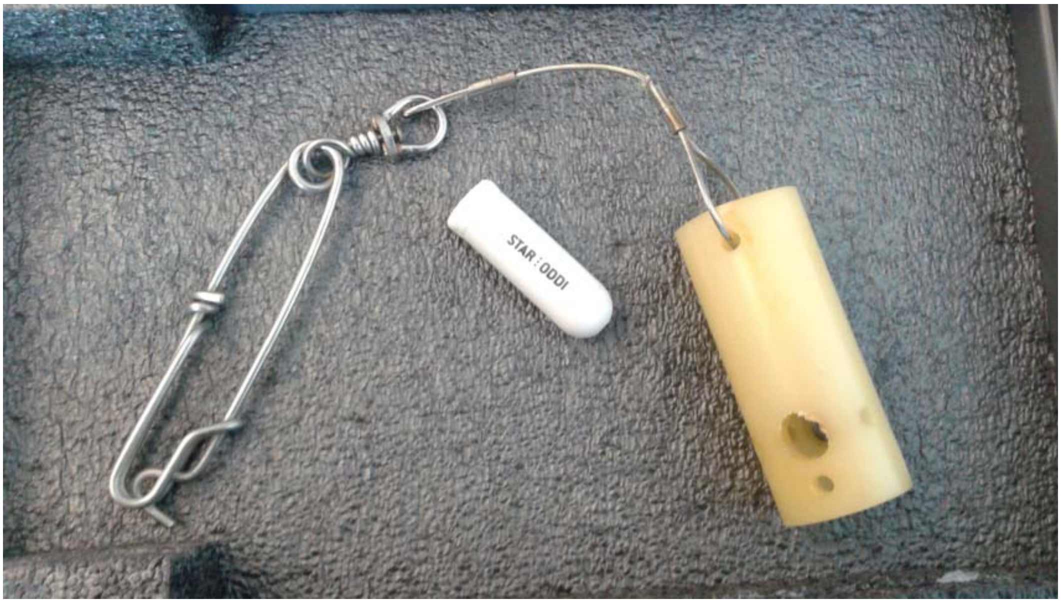

Figure 6. Star-Oddi sensor and housing used in 2012 to reconcile the deepest profiler depth with bottom depth.

finding instruments. Bottom depth was also recorded using the vessel depth-finding instruments and profiler depth was the deepest profiler reading for each cast (Table 2). Depth differences between the profiler and depth-finding instruments of > 20 m were removed from this analysis because it suggested that the profiler rigging may have never contacted the bottom.

Table 2. Summary of depth profiles used in this analysis by vessel. Depth in this table refers to the depth (m) as measured by vessel instruments. Standard deviation shown in parenthesis.

Vessel	Count	Mean diff. between depth and profiler (m)	Variance	Avg. bottom depth of all stations (m)
PSV	58	6.41	4.587	116.0 (42.67)
STW	65	14.60	9.237	163.6 (79.57)
VNI	56	12.43	3.239	122.3 (50.47)
WFL	75	11.01	4.471	151.7 (49.01)

Results

In all, there were 10 active survey vessels in 2012 and each vessel received a sensor. Two of the sensors were lost when the anchors became attached to the bottom and the instruments were pulled free from the anchor using the weak link. Three sensors malfunctioned and no useable data were collected. Data from one sensor was not used because the Star-Oddi values appeared aligned with or were less than the profiler depth data. It is likely that the sensor was either malfunctioning or it had been placed incorrectly on or above the profiling unit instead of the anchor. The four remaining vessels yielded a total of 254 useable bottom depth data points. Figure 7 illustrates the relationship of the three depth data sets used in this analysis.

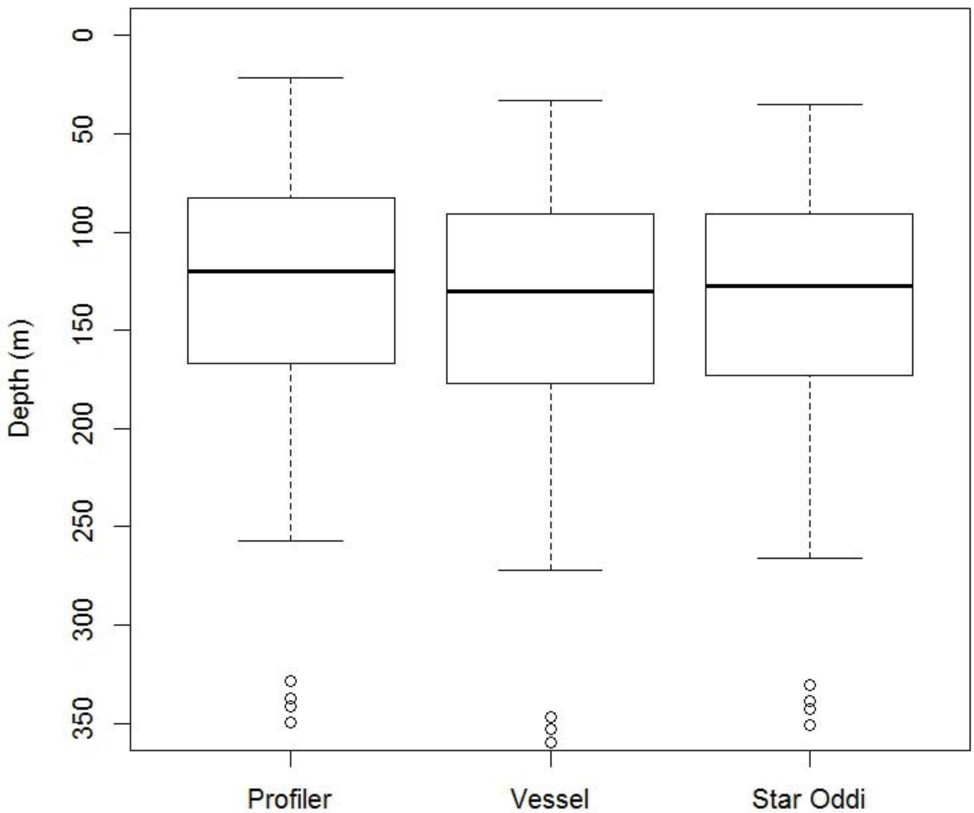

Figure 7. Boxplot of the three datasets used in this analysis: maximum profiler depth, bottom depth as measured by vessel depth-finding instruments, and bottom depth as measured by Star Oddi sensors.

Proximity of the profiler to the bottom during casts

Star-Oddi bottom depth values (O) were compared with the deepest depth readings from the profiler (P) for each cast. Average differences among vessels between O and P were: PSV (4.5 m), STW (9.0 m), VNI (13.2 m), and WFL (3.1 m), which translates to the profiler descending an additional 1.8-11.9 m towards the bottom after the anchor made contact. Using average distance off-bottom in 50-m depth bins showed that the deeper the station, the greater the descent of the profiler after the anchor hit bottom, and thus the closer the profiler came to the bottom (Table 3).

There are clear differences among vessels (Fig. 8) and the reasons for these differences may have one or more explanations including different depth profiles (Table 2), inconsistencies in the length of line between the anchor and profiler, differences in the weight of the anchor, or differences in drag created by the vessels' gurdies as the profilers are deployed. Although there were differences among vessels and the bias appears greater in shallower depths, the relationship of how the profiler performed at different depths was the same across vessels (Fig. 9).

Accuracy of the vessel depth-finding instruments

The conventional method for estimating bottom depth during profiler deployment is to use the vessel's depth-finding instruments (C). To assess the accuracy of C, it was compared to O with the assumption that O was equivalent to true bottom depth. A paired t-test of C and O showed a statistically significant difference between the two measurements (mean difference=4.045 m,

Table 3. Mean distance (m) of the profiler from the bottom, as recorded by the Star Oddi instruments, by vessel and depth. Standard deviation is shown in parenthesis.

Station Depth (m)	PSV	STW	VNI	WFL	Total
0-50	13.5 (n/a)	13.1 (0.53)		5.9 (n/a)	11.4 (3.69)
50-100	6.0 (0.77)	12.1 (0.70)	14.3 (0.36)	4.6 (0.61)	9.6 (4.08)
100-150	4.0 (1.16)	10.4 (0.61)	13.1 (0.67)	3.6 (0.48)	7.0 (4.20)
150-200	1.6 (0.58)	8.3 (0.94)	12.3 (3.05)	2.4 (0.53)	5.2 (4.37)
200-250	0.0 (n/a)	6.5 (0.72)	9.6 (0.25)	1.1 (0.48)	5.2 (3.09)
250-300		5.2 (0.20)	9.0 (n/a)	0.1 (n/a)	4.9 (3.64)
300-350		1.6 (0.08)			1.6 (0.08)
350-400		1.2 (n/a)			1.2 (n/a)
Total	4.5 (2.25)	8.9 (3.08)	13.2 (1.84)	3.1 (1.21)	7.1 (4.47)

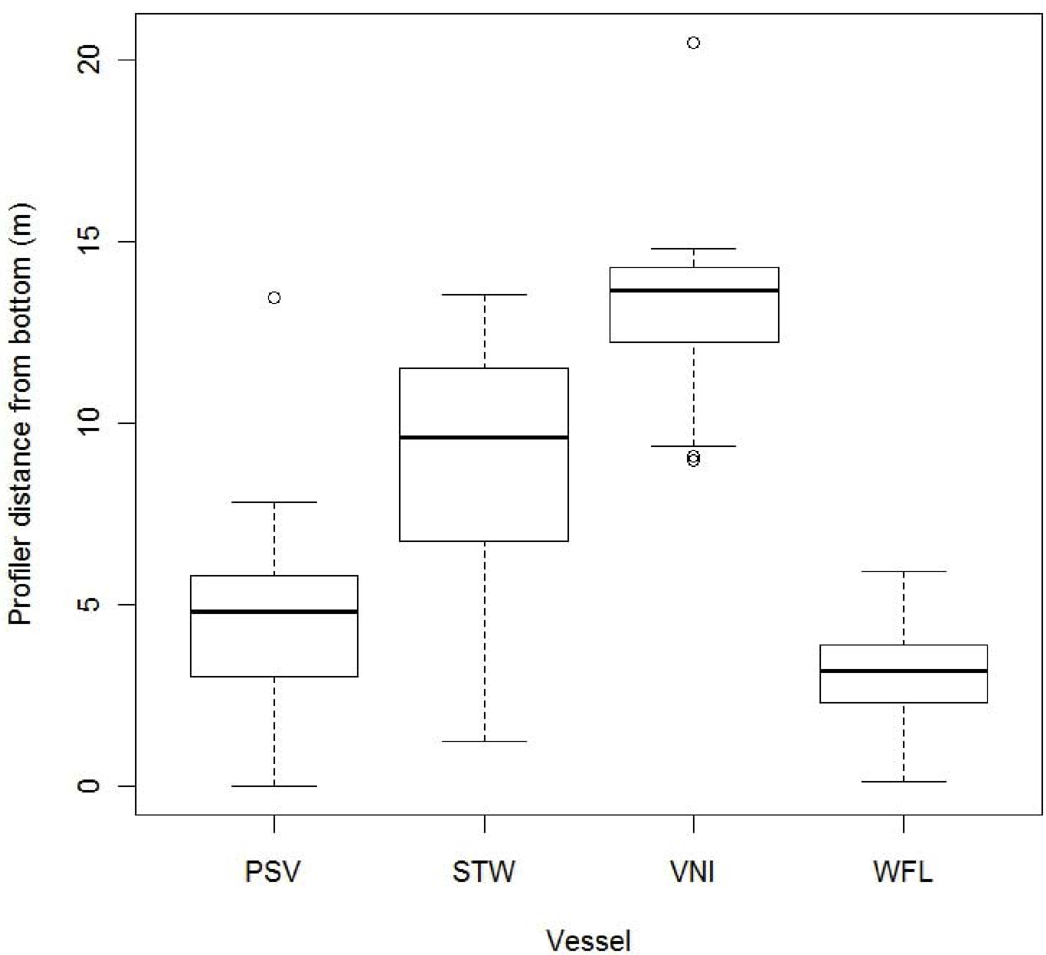

Figure 8. Boxplot of Star Oddi depth minus profiler depth for each of the four fishing vessels in the study: Pacific Surveyor (PSV), Star Wars II (STW), Vanisle (VNI), and Waterfall (WFL).

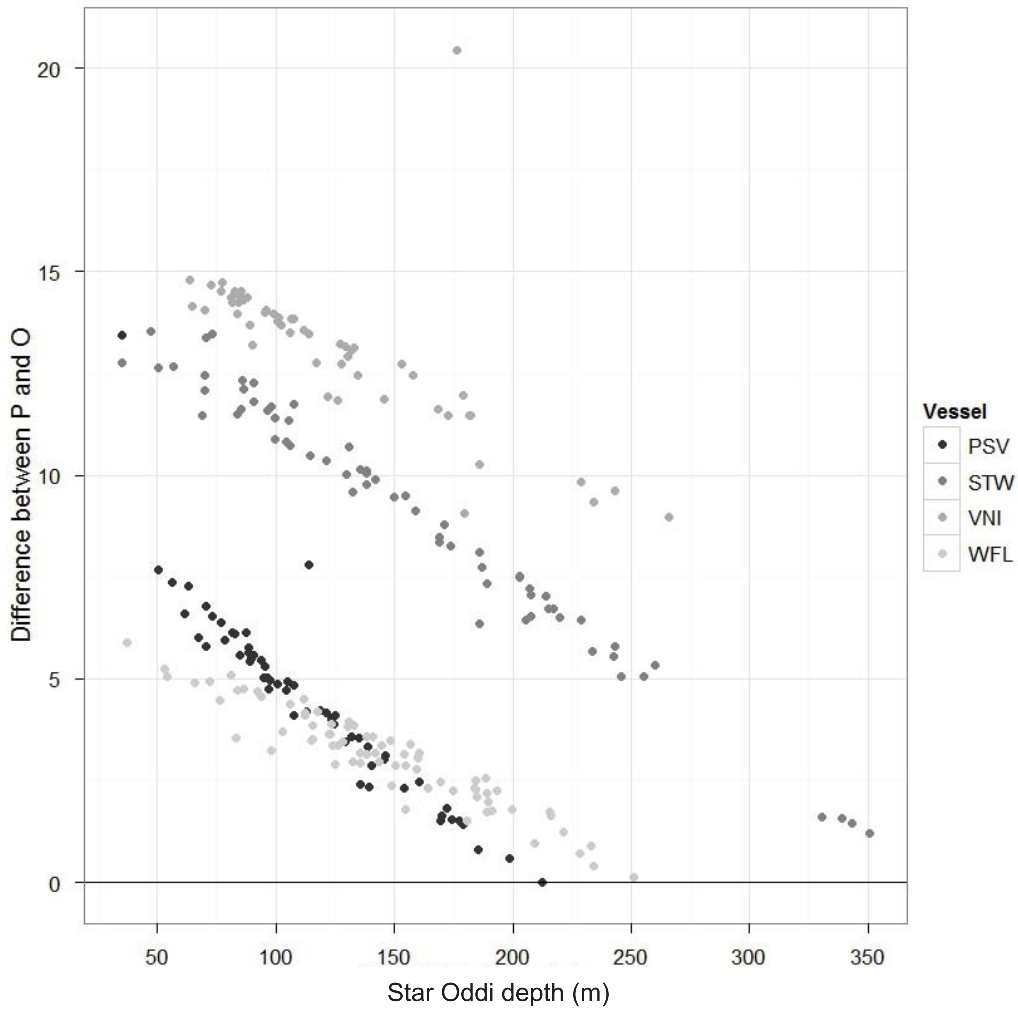

Figure 9. Distance of the profiler from the bottom (m) at the deepest point for each cast. Note that although there is variability among vessels, the relationship of the profilers across depths is the same.

p-value < 0.001). An analysis of covariance was performed using vessel and depth as covariates and the result was that the slopes of the individual vessels were not significantly different from one another. However, a comparison of the differences between C and O by depth reveals that at shallow depths (i.e. < 100 m), the C and O recorded similar depths, but at > 100 m depths, C tended to record a deeper depth than O (Fig. 10).

Variability of depth-finding instruments across vessels

In order to assess the variability of the depth-finding instruments across vessels, data from all 10 vessels that participated in the 2012 survey were used (Fig. 11). Analysis of variance indicated that there was a significant difference between C-P across vessels. To examine the differences between each pair of vessels more closely, a TukeyHSD test was performed (Table 4). This test revealed that 33 of 45 possible vessel combinations indicated significant differences (with the Bonferroni correction applied to the alpha level of 0.05). Mean differences ranged from <1 m to slightly more than 8 m.

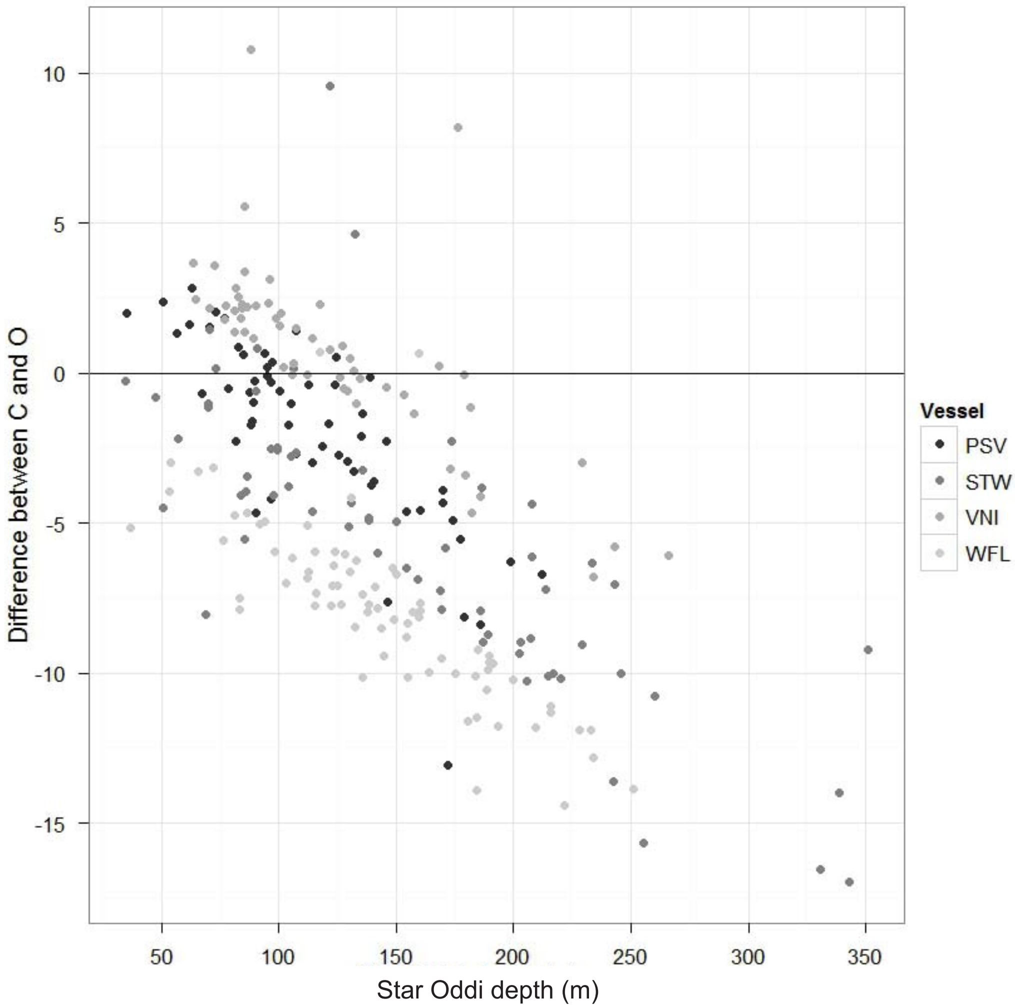

Figure 10. The difference between the vessel depth-finding instruments and what was recorded by the Star Oddi (O-C). This shows that at shallow depths, the measurements were similar, but at deeper depths, the vessel instruments tended to overestimate the bottom depth.

A mixed effects model was used to determine the relationship between profiler depth and vessel recorded depth while accounting for vessel differences (Table 5). The model fitted was:

$$P=\alpha+\beta C+\boldsymbol{\upsilon}\mathbf{V}$$

where α is the intercept, β is the slope of the relationship with bottom depth as measured by the vessel (C), υ is a vector of random effects for the vessels, and V is the design matrix for the vessels. The variables of interest are the intercept (α) and slope (β), which determine the relationship between C and P at different depths, integrated over all vessels.

The intercept (the difference at a depth of zero) was about 9.0 m, which is less than the 11.1 m median difference when neither vessel nor depth are taken into account (Fig. 11a). A depth of 150 m would predict a difference of 11.1 m. The slope was slightly less than one (0.986) indicating a slightly greater bias at deeper depths, although the relationship is fairly consistent across depth (even though the slope is significantly different than 1.0). The variance of the vessel random effect was significantly greater than zero, indicating that there are differences across vessels.

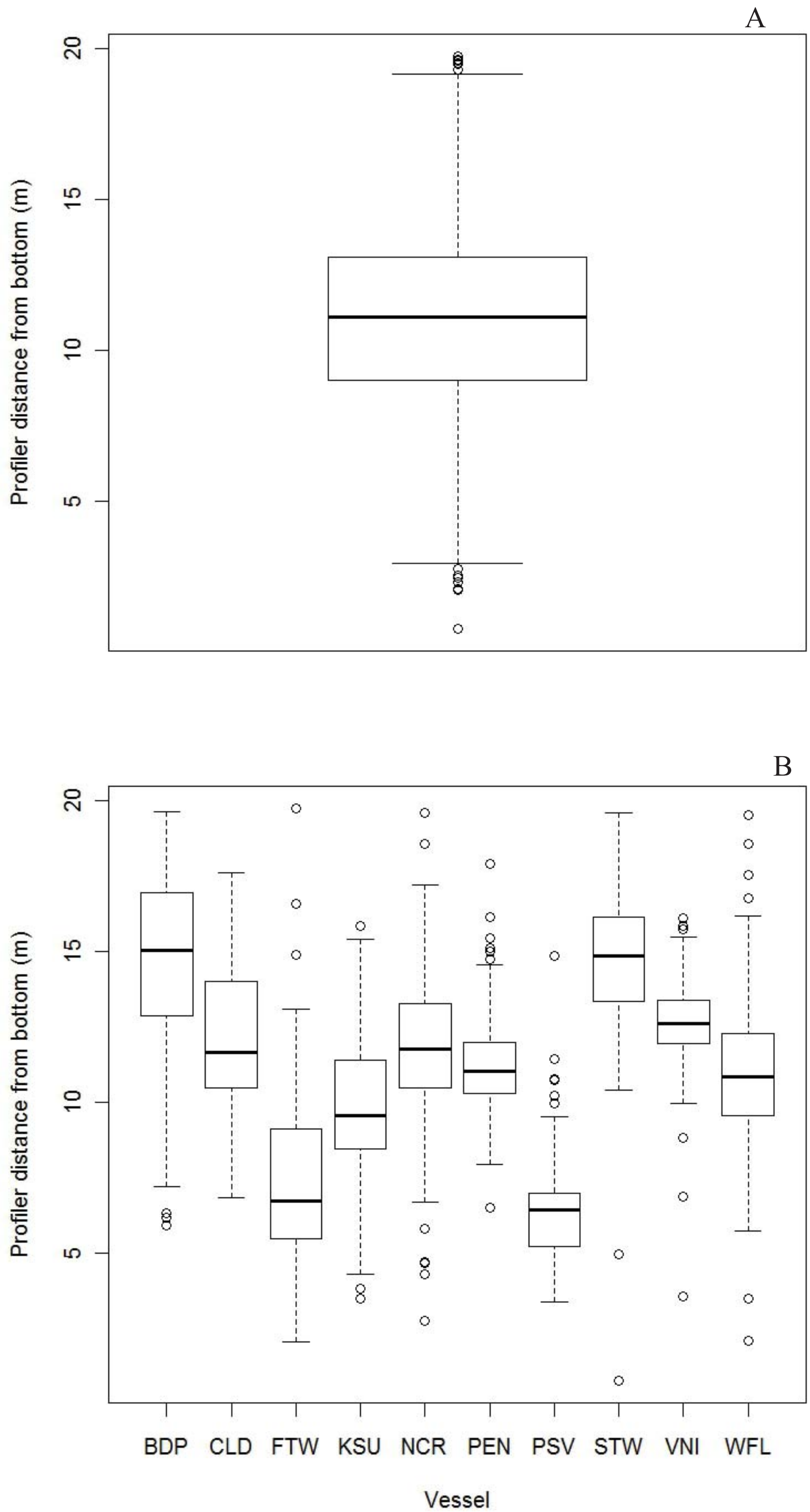

Figure 11. Boxplots describing the profiler's distance from the bottom at the maximum recorded profiler depth as recorded by vessel instruments: A) all vessels combined and B) by individual vessel.

Table 4. Results of a TukeyHSD comparison of average differences (C-P) between vessels. In 73% of the cases (with the Bonferroni correction applied to the alpha level of 0.05 yielding a significance level of 0.0011), the differences are statistically significant (shown in boldface type).

Vessel combination	Difference	Confidence Interval Lower	Confidence Interval Upper	p_{adj}-value
FTW-PSV	0.879070	-0.23311	1.991253	0.266212
KSU-PSV	**3.515486**	2.351600	4.679372	<0.0001
WFL-PSV	**4.555961**	3.461556	5.650367	<0.0001
PEN-PSV	**4.787028**	3.672038	5.902018	<0.0001
NCR-PSV	**5.250638**	4.001410	6.499866	<0.0001
CLD-PSV	**5.616547**	4.150981	7.082112	<0.0001
VNI-PSV	**6.112064**	4.966160	7.257968	<0.0001
STW-PSV	**7.996661**	6.709692	9.283630	<0.0001
BDP-PSV	**8.022535**	6.819162	9.225908	<0.0001
KSU-FTW	**2.636416**	1.646129	3.626703	<0.0001
WFL-FTW	**3.676891**	2.769278	4.584504	<0.0001
PEN-FTW	**3.907957**	2.975626	4.840289	<0.0001
NCR-FTW	**4.371568**	3.282252	5.460884	<0.0001
CLD-FTW	**4.737476**	3.405590	6.069362	<0.0001
VNI-FTW	**5.232993**	4.263904	6.202083	<0.0001
STW-FTW	**7.117591**	5.985192	8.249990	<0.0001
BDP-FTW	**7.143464**	6.107055	8.179874	<0.0001
WFL-KSU	1.040475	0.070196	2.010754	0.024329
PEN-KSU	1.271542	0.278102	2.264981	0.002153
NCR-KSU	**1.735152**	0.593098	2.877207	<.001
CLD-KSU	**2.101061**	0.725706	3.476415	<.001
VNI-KSU	**2.596578**	1.568563	3.624592	<0.0001
STW-KSU	**4.481175**	3.297956	5.664394	<0.0001
BDP-KSU	**4.507049**	3.415341	5.598756	<0.0001
PEN-WFL	0.231066	-0.67999	1.142118	0.998527
NCR-WFL	0.694677	-0.37648	1.765836	0.559063
CLD-WFL	1.060585	-0.25649	2.377663	0.241680
VNI-WFL	**1.556102**	0.607468	2.504737	<.001
STW-WFL	**3.440700**	2.325756	4.555644	<0.0001
BDP-WFL	**3.466573**	2.449264	4.483882	<0.0001
NCR-PEN	0.463611	-0.62857	1.555793	0.942612
CLD-PEN	0.829519	-0.50471	2.163750	0.619525
VNI-PEN	**1.325036**	0.352725	2.297346	<0.001
STW-PEN	**3.209633**	2.074477	4.344790	<0.0001
BDP-PEN	**3.235507**	2.196085	4.274929	<0.0001
CLD-NCR	0.365908	-1.08238	1.814197	0.998571
VNI-NCR	0.861425	-0.26230	1.985149	0.308570
STW-NCR	**2.746023**	1.478763	4.013283	<0.0001
BDP-NCR	**2.771896**	1.589625	3.954168	<0.0001
VNI-CLD	0.495517	-0.86465	1.855688	0.978611
STW-CLD	**2.380115**	0.899149	3.861080	<.001
BDP-CLD	**2.405988**	0.997060	3.814915	<.001
STW-VNI	**1.884597**	0.719062	3.050133	<.001
BDP-VNI	**1.910471**	0.837955	2.982987	<.001
BDP-STW	0.025873	-1.19621	1.247955	1.000000

Table 5. Results of the mixed effects model integrating across vessels.

Random effects:					
Groups	Name	Variance	Std. dev.		
Vessel	Intercept	6.4942	2.5484	Number of obs.	1026
Residual		4.7846	2.1874	Number of vessels	10
Fixed effects:					
	Estimate	Lower CI	Upper CI		
Intercept	-9.0426	-10.7211	-7.3660		
Model coefficient (slope)	0.9862	0.9845	0.9878		

Conclusions for bottom depth

This analysis illustrates that there is variability in how far the profiler descends after the anchor has hit bottom as well as varying accuracy in the vessel depth-finding instruments. Total bottom depth is clearly a factor in how far the profiler descends after the anchor has hit bottom in that the profiler's distance from the bottom decreases with increasing depth. Interestingly, the bias of the vessel depth-finding instruments shows a positive correlation with depth, i.e. the difference between the profiler depth and depth recorded from vessel-finding instruments increases slightly with increasing depth. Depth-finding instrument differences among vessels are also statistically significant in many cases. Overall though, while there are absolute differences among vessels the relationship of the profiler to bottom depth is consistent across vessels and areas.

In conclusion, the profiler's distance from the bottom decreases with increasing depth but that difference is offset somewhat in the data because the vessel instruments are more likely to overestimate bottom depth at increasing depth. Ultimately, the original estimate that the profiler descends to an average of about 10 m from the bottom seems reasonable with a range of 5-15 m in most cases. Pacific halibut are demersal animals swimming near the bottom with occasional forays higher into the water column. The bottom-most readings of the profiler are therefore a reasonable indicator of halibut habitat conditions.

Profiler data collected through 2014

A profile cast was considered successful if depth (pressure), temperature, and salinity (conductivity) data were collected over the majority of the water column. The goal was to collect data vertically from near the surface until the anchor hit bottom. Occasionally the profiler shut itself down mid-cast due to a loose switch or moisture in the connector. Additionally, there were times when the profiler was pushed horizontally through the water due to strong currents, and it was likely that the bottom was never contacted. In all cases, the cast was still considered successful if the majority of the water column was profiled. Casts that did not appear to contact the bottom were noted in the metadata. When auxiliary sensors malfunctioned, i.e. dissolved oxygen, pH, and fluorescence, those variables were deleted from the record, but the core variables were retained.

Through 2014, a total of 8,008 profiles were successfully completed coast wide (Table 6). From 2009, roughly 90% of the stations possible were successfully profiled. The most common reasons for not completing a profile were poor weather resulting in no attempt, and unit malfunction.

Pacific halibut environmental habitat

Pacific halibut are a demersal species and the deepest readings of the profilers directly describe the conditions experienced by the fish caught on the survey gear. These six years

Table 6. Number of water column profile casts successfully completed during the IPHC setline survey 2000-2014. Refer to Figure 1 for a description of survey and regulatory areas.

IPHC survey region	Reg Area	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Total
N. California	2A														14	16	30
Oregon	2A								41	41	42	42	53	31	44	31	325
Washington	2A								15	40	59	42	57	48	57	52	370
Puget Sound	2A												14			10	24
Vancouver	2B						38	34	35	40	41	41	37	41	40	36	383
Goose Island	2B						36	38	37	24	43	43	40	42	42	37	382
St. James	2B									39	41	42	37	39	42	38	278
Charlotte	2B							41		38	42	41	42	40	44	44	332
Ketchikan	2C							36	40		38	37	41	21	35	34	282
Ommaney	2C						38				40	39	37	39	30	37	260
Sitka	2C	39					4				42	42	42	39	40	41	289
Fairweather	3A	45									49	48	29	47	23	41	282
Yakutat	3A	48									51	51	48	48	32	40	318
Prince William Sound	3A										45	45	45	45	25	45	250
Seward	3A					12					44	48	46	47	32	48	277
Gore Point	3A										43	45	44	45	26	44	247
Portlock	3A		29								46	43	45	26	45	42	276
Shelikof	3A		21			2					45	38	44	42	32	44	268
Albatross	3A		45	25							33	44	44	45	28	45	309
Trinity	3B		4								47	44	46	42	47	29	259
Semidi	3B		20								47	41	40	47	46	44	285
Chignik	3B										44	42	47	42	44	42	261
Shumagin	3B										43	0	35	12	42	43	175
Sanak	3B										48	28	48	38	41	48	251
Unalaska	4A										64	51	61	55	52	81	364
4A Edge	4A, 4C				36						57	56	42	33	37	81	342
4D Edge	4D				48						68	57	63	43	24	61	364
Adak	4B										43	44	25	42	43	42	239
Attu	4B				41						40	44	41	44	36	40	286
Total	All	132	119	25	125	14	116	149	168	222	1,245	1,138	1,193	1,083	1,043	1,236	8,008

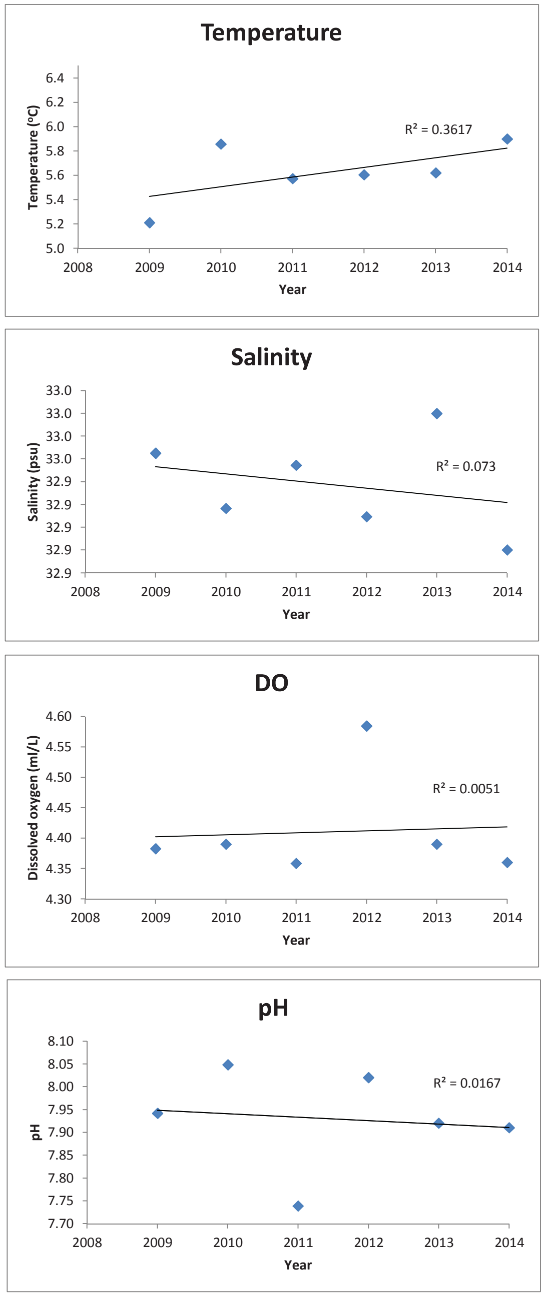

Figure 12. Environmental conditions (temperature, salinity, dissolved oxygen, and pH) on the halibut grounds coastwide as measured by Sea-Bird water column profilers during the IPHC setline survey from 2009-2014. Results reflect the bottom-most readings from the profilers which are considered the conditions experienced by the fish caught on the adjacent gear.

of oceanographic data collection (2009-2014) show that conditions on the halibut grounds varied from year to year, with some trends over time or geographic extent. Coast-wide, near-bottom temperatures warmed over the sampling period (Fig. 12). This finding coincides with the increasing temperature trend of surface waters documented both in the north Pacific and globally (Xue et al. 2014). Both salinity and pH have been highly variable, but overall may be decreasing slightly. Climate projections indicate that salinity is expected to vary regionally due to changes in precipitation, evaporation, and ice melt (Durack et al. 2012) and pH is expected to decrease (i.e. become more acidic) over time (Mellilo et al. 2014). Projections by Shaffer et al. (2009) indicate that globally, ocean dissolved oxygen concentration will decrease over time. The 6-year IPHC dataset shows variability, but no obvious trends as of yet for dissolved oxygen on the halibut grounds.

Pacific halibut are found across a large area encompassing a wide range of oceanographic properties and environmental systems. Based on geographic location and similarities of data collected by IPHC profilers, these can be divided loosely into three oceanographic regions: west coast, Gulf of Alaska, and Bering Sea/Aleutian Islands (Fig. 13). Relative to the other areas surveyed, the west coast summer halibut habitat (near bottom) is characterized by higher temperatures, lower dissolved oxygen with hypoxia occurring in places (hypoxia is defined as ≤1.4 ml/L), lower pH, and higher salinity. The Gulf of Alaska tends toward cooler temperatures, higher dissolved oxygen, higher pH, and lower salinity than the west coast region. In the Bering Sea, halibut are found over a broad area from inner Bristol Bay to the shelf edge, but in most years, the survey covers only the shelf edge and habitat around the Pribilof Islands and St. Matthew Island as well as both the north and south sides of the Aleutian Island chain. The monitored habitat is characterized by cooler temperatures, high dissolved oxygen except at very deep stations, pH similar to the Gulf of Alaska (but higher than the west coast), and salinity that is lower than the west coast region but higher than the Gulf of Alaska. Figure 14 illustrates these differences by region and over time. Table 7 shows the average and range of temperature, salinity, dissolved oxygen, and pH values for each region and year.

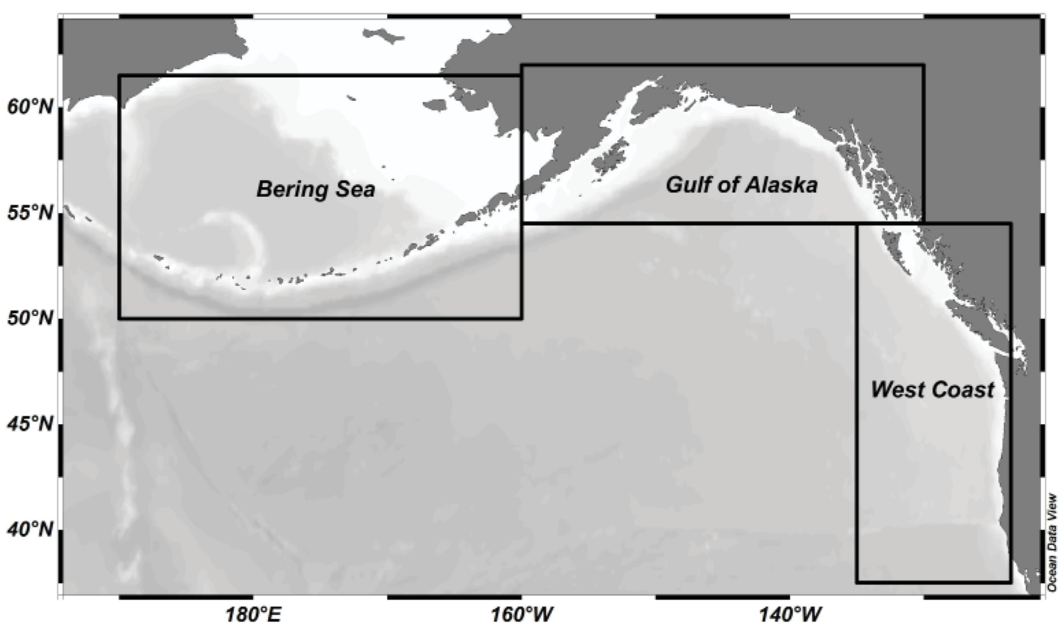

Figure 13. The area surveyed was divided into three broad study areas with unique oceanographic and habitat characteristics: West Coast, Gulf of Alaska, and Bering Sea/ Aleutian Islands.

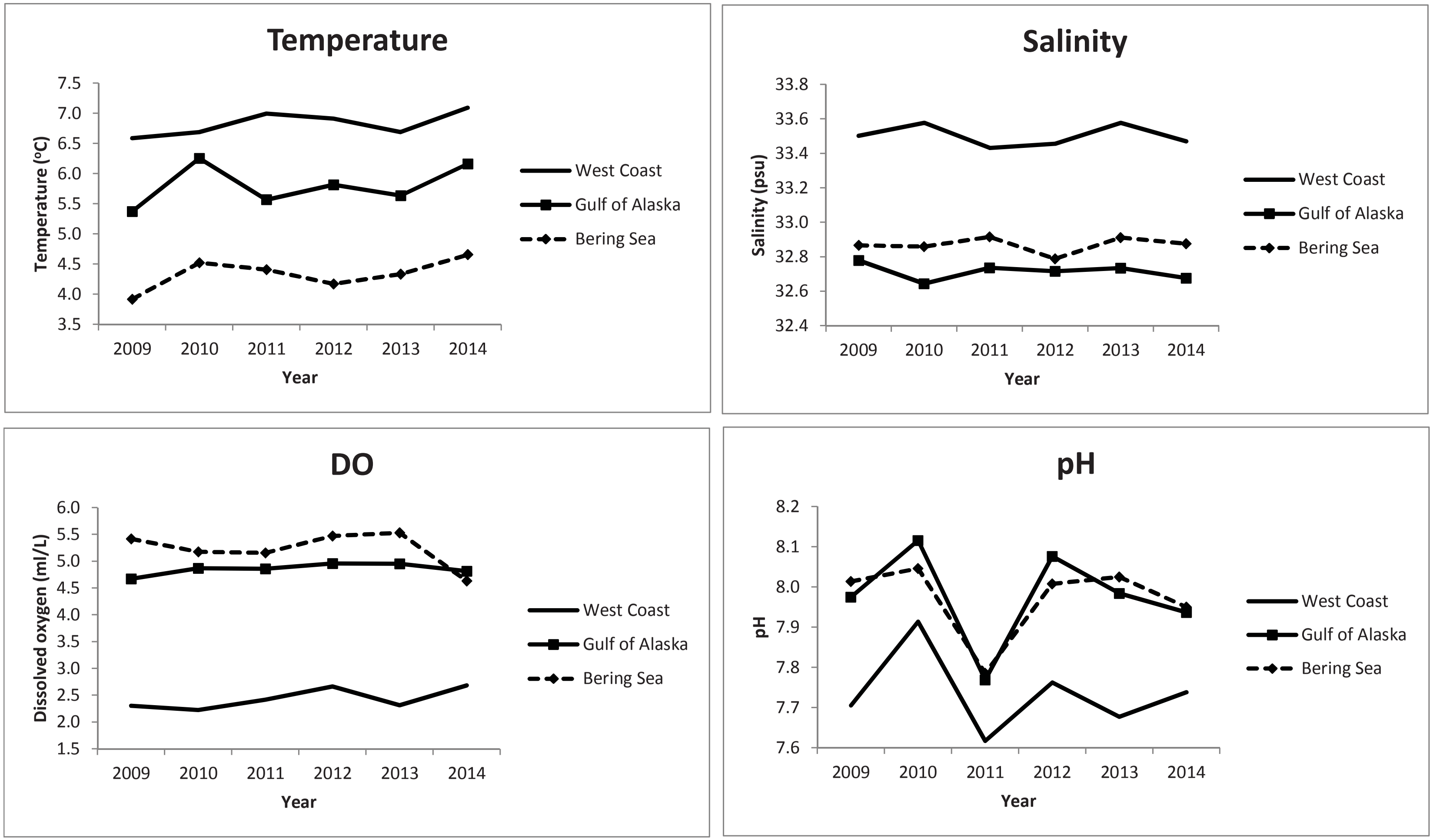

Figure 14. Average environmental conditions (temperature, salinity, dissolved oxygen (DO), and pH) on the halibut grounds as measured by Sea-Bird water column profilers during the IPHC setline survey from 2009-2014 for each of the three areas defined in Figure 13. Results reflect the deepest readings from the profilers which are considered the conditions experienced by the fish caught on the adjacent gear.

Table 7. Near-bottom mean and range of temperature (°C), salinity (psu), dissolved oxygen (ml/L), and pH measurements collected during the IPHC setline survey, June-August of 2009-2014.

	Temperature				Salinity			
West Coast	Mean	Std Dev	Min	Max	Mean	Std Dev	Min	Max
2009	6.59	0.844	4.8	10.5	33.50	0.924	26.4	34.1
2010	6.69	1.044	4.8	10.0	33.58	0.536	31.8	34.1
2011	7.00	1.081	4.5	10.9	33.43	0.906	29.0	34.3
2012	6.91	1.039	4.8	10.6	33.46	0.671	30.9	34.1
2013	6.69	1.020	4.8	11.0	33.58	0.638	28.4	34.2
2014	7.09	1.251	5.1	13.6	33.47	0.665	31.1	34.1
Gulf of Alaska								
2009	5.38	0.989	2.6	10.0	32.78	0.621	29.1	34.1
2010	6.25	1.024	3.9	10.8	32.64	0.642	30.0	34.0
2011	5.57	0.734	3.2	9.8	32.74	0.631	30.7	34.0
2012	5.82	1.003	3.4	9.3	32.72	0.639	30.1	34.1
2013	5.64	0.957	3.4	10.3	32.74	0.635	30.8	34.1
2014	6.16	1.123	4.1	10.9	32.68	0.647	28.9	34.1
Bering Sea/Aleutians								
2009	3.92	1.040	0.2	6.3	32.87	0.635	31.3	34.1
2010	4.52	1.198	-0.3	7.3	32.86	0.688	30.9	34.2
2011	4.41	0.999	-0.3	7.6	32.92	0.628	31.1	34.2
2012	4.17	1.542	-1.4	9.6	32.79	1.018	26.1	34.1
2013	4.33	0.923	1.5	6.7	32.91	0.563	31.7	34.1
2014	4.66	1.092	0.0	9.7	32.88	0.587	29.6	34.1

	Dissolved oxygen				pH			
West Coast	Mean	Std Dev	Min	Max	Mean	Std Dev	Min	Max
2009	2.30	1.334	0.7	7.6	7.71	0.115	7.5	8.1
2010	2.23	1.069	0.6	5.7	7.91	0.164	7.6	8.3
2011	2.42	1.260	0.3	6.3	7.62	0.135	7.4	8.1
2012	2.66	1.362	0.5	6.2	7.76	0.072	7.7	8.1
2013	2.31	1.062	0.5	5.8	7.68	0.182	7.3	8.3
2014	2.69	1.176	0.9	6.1	7.74	0.138	7.6	8.5
Gulf of Alaska								
2009	4.67	1.642	0.6	8.6	7.98	0.175	7.6	8.4
2010	4.87	1.523	0.6	7.6	8.12	0.163	7.6	8.4
2011	4.86	1.617	0.7	7.4	7.77	0.148	7.4	8.1
2012	4.96	1.502	0.5	7.9	8.08	0.197	7.4	8.6
2013	4.95	1.659	0.6	8.4	7.98	0.171	7.4	8.3
2014	4.82	1.405	0.7	10.7	7.94	0.168	7.2	8.4
Bering Sea/Aleutians								
2009	5.42	1.491	0.5	7.7	8.01	0.165	7.5	8.4
2010	5.18	1.429	0.4	7.4	8.05	0.182	7.4	8.4
2011	5.15	1.548	0.4	8.0	7.79	0.175	7.4	8.1
2012	5.47	1.576	0.4	8.9	8.01	0.224	7.4	8.4
2013	5.53	1.467	0.6	7.5	8.03	0.148	7.6	8.3
2014	4.63	1.955	0.3	8.2	7.95	0.150	7.6	8.3

Chlorophyll is almost always zero on the halibut grounds because it exists only in the photic zone of the water column which is near the surface in the first 100 m or so and most frequently within the first 50 m. IPHC collects chlorophyll concentration data with the intention of calculating depth integrated values for chlorophyll during the summer months. These data may contribute to early life history and predator/prey interaction studies in the future.

Profiler deployment reports are written annually and include iso-surface maps of the bottom habitat from data collected with the profilers during the survey. These reports can be found in the Report of Assessment and Research Activities on the IPHC website: http://www.iphc.int/library/raras.html.

Profiler project future

The IPHC plans to continue annual coast-wide environmental monitoring as part of the setline survey into the foreseeable future, and to make the data available to researchers both inside and outside the IPHC. Annual program costs include factory maintenance and calibration, gear set-up, transport of the instruments and gear to and from the field, supplemental supply costs, laptop maintenance, repair/replacement of both the profilers and laptops, and data processing.

As of the writing of this report, the IPHC is beta testing a data capture system using tablets both in the ports and on board survey vessels, which may eventually be the preferred method of data capture from the profilers. However, for the next several years, the companion laptops will continue to be used as either the primary or backup source for profiler data.

One barrier that IPHC scientists have had when using the environmental data is that these data are not yet integrated into the IPHC database system and not easily linked with other data, e.g. catch data from the survey. Without this linkage, environmental data are not readily available for stock assessment, harvest policy, or other analyses. An effort is underway to incorporate these data into the IPHC relational database system and to add calculated metrics such as depth-integrated values for temperature and chlorophyll concentration, among others. Once this is accomplished, IPHC scientists will commence looking at the relationship between environment and biological processes such as growth, reproduction, and migration of Pacific halibut.

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It has taken many people to make the coastwide profiler project successful. Thank you to Dr. Bruce Leaman for the foresight in realizing how valuable and necessary environmental data would be to fisheries in a changing climate, and to Dr. Phyllis Stabeno for helping to make this data collection endeavor a possibility. We would like to thank our external funding sources; the Oregon Department of Fish and Wildlife Restoration and Enhancement program for the funding to purchase a profiler in 2007 which paved the way for a much larger grant a couple of years later from NOAA which enabled us to equip all of our survey vessels. Thanks to all of the field biologists and survey vessel captains and crew, for expertly deploying the profilers at every station, and for sometimes taking extra steps to ensure their safe return to the vessel after each deployment. In constructing this report, we extend thanks to Tom Kong for figure assistance, Claude Dykstra and Dana Rudy for their helpful reviews of the manuscript, and a special thank you to Dr. Allan Hicks for his review and invaluable assistance with the vessel depth analysis.

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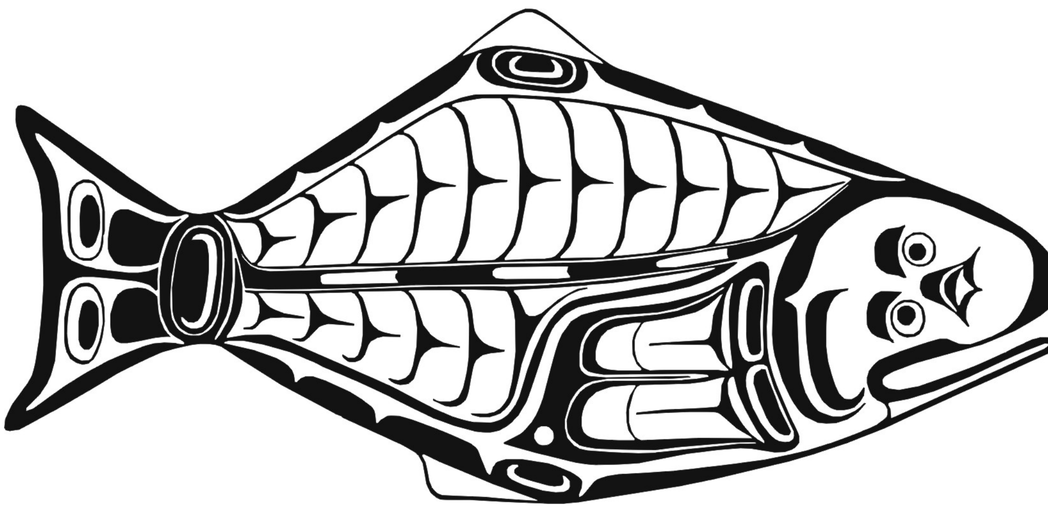

Halibut Crest - adapted from designs used by Tlingit, Tsimshian and Haida Indians